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Nanopatterning of Polymer Replication Tools

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Motivation

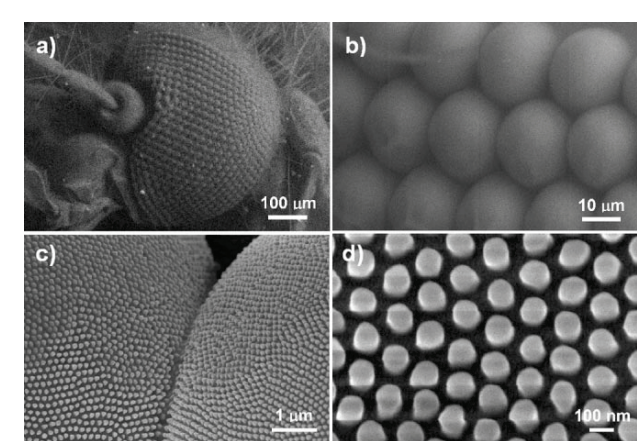


Figure 1. The antifogging surface of mosquito eyes [1].

The nanostructured surfaces, inspired by those seen in nature (Fig 1.) provide a broad range of advanced functionalities, such as stunning structural colors, antireflective, self-cleaning, superhydrophobic, superhydrophilic or antifogging effects. Those effects are facilitated by the specific arrangement of micro- and nanostructures on the surface. Artificial nanostructured surfaces are usually limited to a flat, planar substrates.

Injection molding, a widely used fabrication technique, is capable of replicating extremely small structures, but also of producing parts with complex, non-

planar shapes, at very affordable cost. In order to use injection molding for making products with nanostructured surfaces, we need to fabricate molds facing the same problem.

In this work, we address this problem. By using a hydrostatic nanoimprinting technique, with hydrogen silsesquioxane (HSQ) films (Fig 2.) deposited by a spray-coating method on flat and non-planar curved mold inserts. The cured HSQ films are durable and tough, which makes them good candidates for molds, but the imprinting of such high viscosity films as the HSQ dictates the use of

extreme pressures, up to 800 bar, and the use of nanopatterned nickel masters. We also need to characterize the pattern distortion due to conforming of a planar master to a non-planar substrate coated by the HSQ layer.

If the nanostructured molding surfaces can be formed, we can mass produce functional nanopatterned surfaces on injection molded plastic products. This allow to facilitate introduction of new products, and to improve properties of common items used in a daily life.

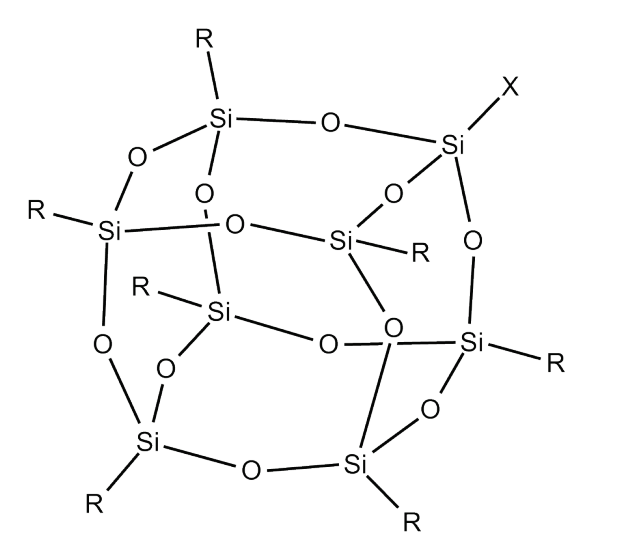


Figure 2. The structure of a hydrogen silsesquioxane. R, X=H.

Methods

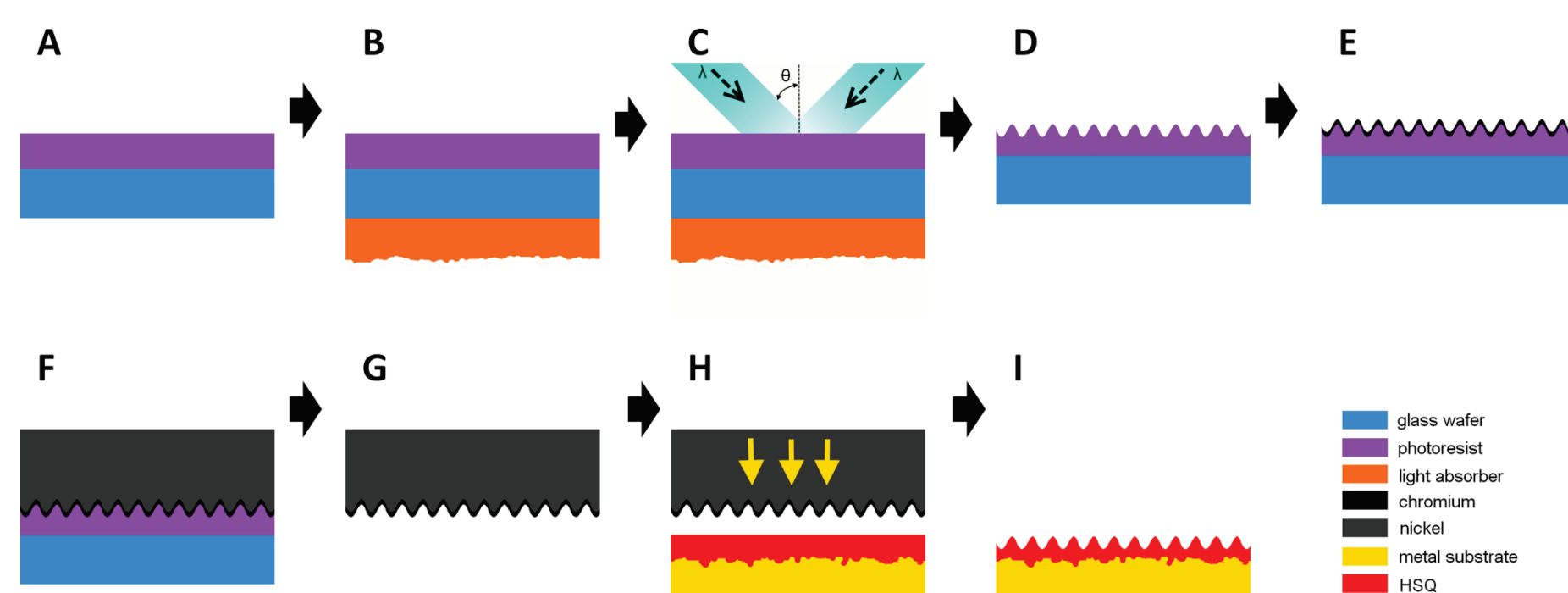


Figure 3. Schematic process flow. A-D. Preparation of a 426 nm pattern in resist. E-G. Electroplating to form a flexible nickel master. H-I. High pressure nanoimprinting into HSQ.

The Ni masters for pattern transfer are created using interference lithography as shown in Figure 3. Two exposures yield a perfectly regular cross-grating with a period of 426 nm. Briefly, an AZ5214E resist is spin-coated onto a glass wafer (A), then a backside absorber is deposited (B). The exposures are carried out using a He-Cd laser (C), resist is developed (D) and a 60 nm chromium seed layer is deposited (E). The layer is electroplated to form the Ni foil (F), which is then cleaned (G) and used either directly or as a tool to imprint into HSQ (H) at the hydrostatic pressure of 600-800 bar. The nanopatterned HSQ resist on the mold insert (I) is then cured and can be used for injection molding of polymer parts.

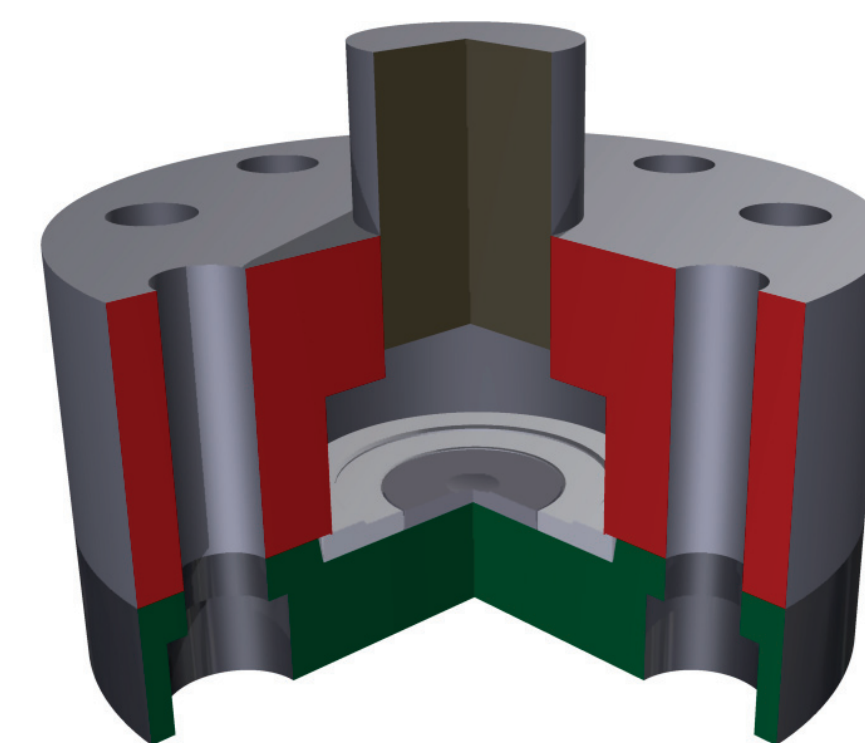


Figure 4. The high pressure hydrostatic nanoimprint device. The piston is forced into the cavity, filled with PDMS and the resulting pressure imprints the master into the HSQ film on a freeform substrate

The device needed to deliver this extremely high hydrostatic pressure was specially developed and is shown on Figure 4. It uses a PDMS disk in the cavity as a pressure transfer medium.

Figure 5 shows prepared nickel masters. If the thickness is high, 300-350 μm , one can use the foils directly as a mold insert, if the thickness is low, say 25-100 μm , foils are flexible, and can be used to transfer patterns onto non-planar substrates.

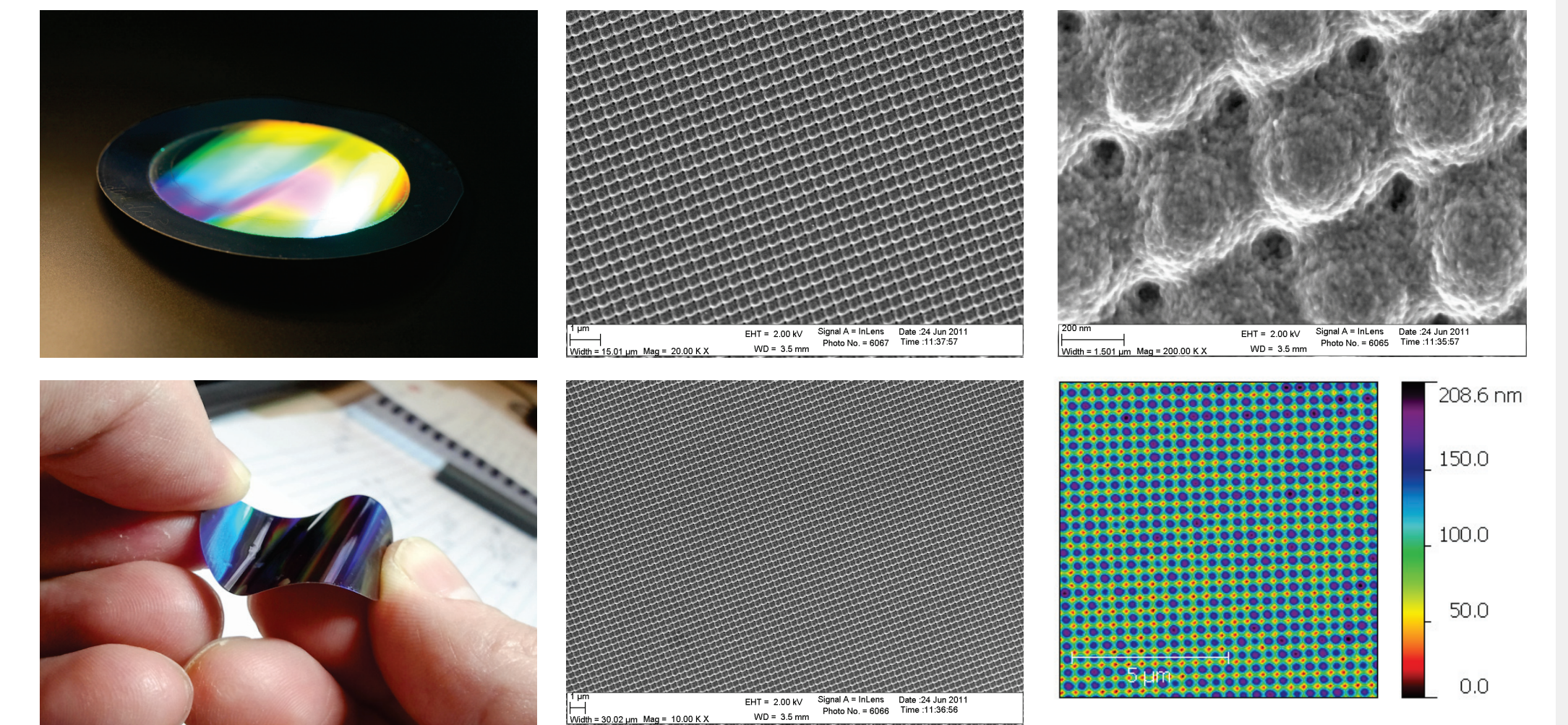


Figure 5. Prepared nickel master with cross-grating nanopattern. Photos, SEM and AFM.

Results



Figure 6. Ni master can be used directly, to injection mold plastic parts with structural colors, as seen on the bottom panel.

Figure 6 shows injection molded TOPAS polymer chips, with the logo of The Danish National Advanced Technology Foundation in structural colors. It is created in one injection molding step, with the same polymer. We used a simple, laser cut shadow mask and exact same lithographically created grating pattern as before.

Figure 7 shows a selection of non-planar, highly curved surfaces with nanoimprinted patterns. They can be used directly as mold inserts for injection molding. We demonstrated a feasibility of pattern (period of 426 nm) transfer on a double-curved spherical cap surface with the radius of curvature as low as 0.5 mm.

We have been able to calculate and measure the pattern distortion. The nanopattern strain is a result of an intrinsically planar stamp brought in a contact with a spherical cap surface. Results from a numerical model are in a good agreement with observed strain as can be seen in last two columns of figure 7.

Acknowledgement

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[1] X. Gao *et al*, The dry-style antifogging properties of mosquito compound eyes and artificial analogues prepared by soft lithography, Adv Mater. 19 (2007) 2213. doi:10.1002/adma.200601946.

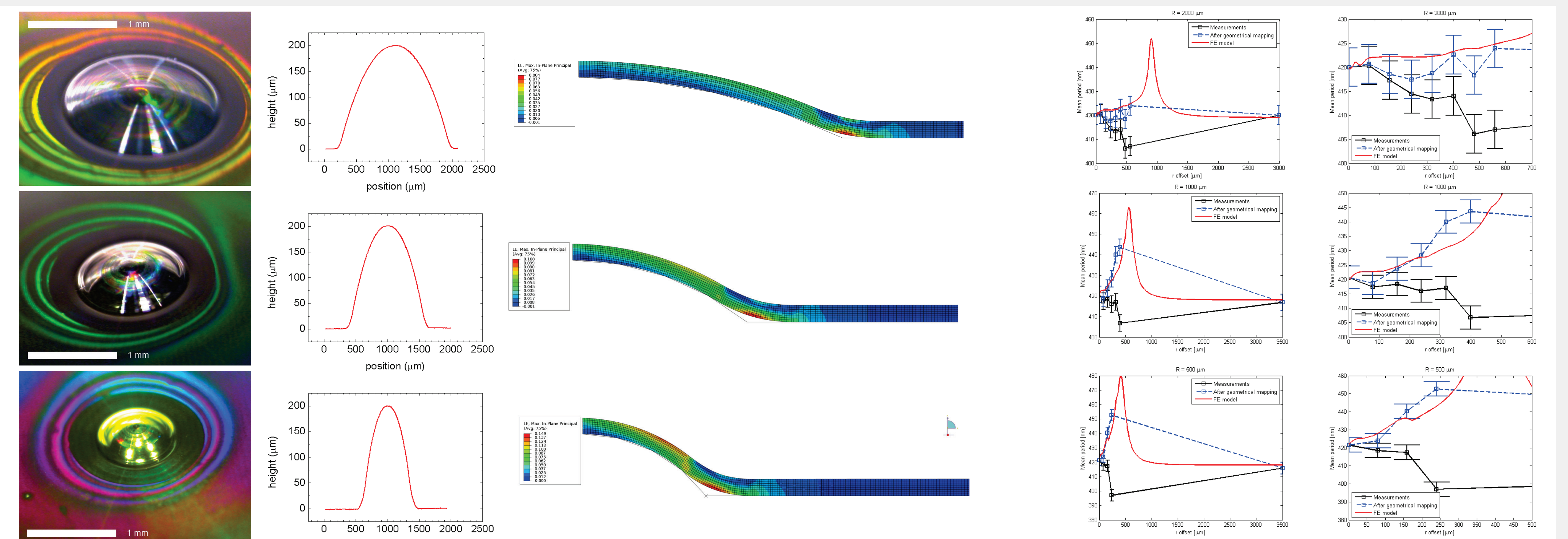


Figure 7. Nanopatterned non-planar surfaces, spherical caps with radii 2000, 1000 and 500 μm . The left column shows low magnification micrographs, demonstrating diffraction effect due to nanopattern, the next are profiles as measured by a stylus profiler, the next are contour plots showing strain of deformed foil, and the next are measured strains devised from pattern period, compared to the model.

